Effects of Residual Arsenic Incorporation during Gas-Source MBE Growth of InGaAsP Waveguides

Susan Wey, Régis André, and Charles Tu
Department of Electrical and Computer Engineering
University of California, San Diego
9500 Gilman Dr., La Jolla, CA 92093

During a preliminary study of the growth of InP/InGaAsP/InP waveguide structures by gas source molecular beam epitaxy, it was discovered that a significant amount of unintentional incorporation of arsenic into InP layers directly above and below the quaternary layer can occur. This resulted in anomalous X-ray scans, as shown in Fig. 1, even when photoluminescence results and reflection high energy electron diffraction patterns indicated good material quality.

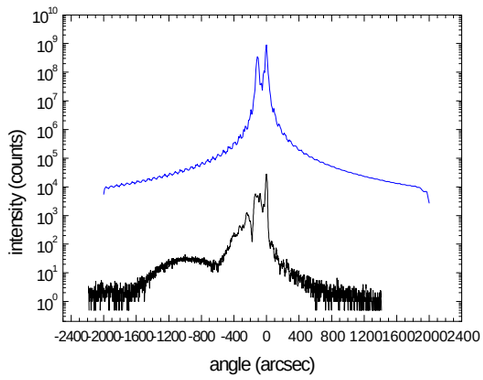

Fig.1. X-ray data for InP/InGaAsP/InP waveguide structure. Top: simulation of quaternary layer with no As leaks in buffer or cap layers. Simulated structure is InP 1420Å buffer/ $In_{0.7}Ga_{0.29}As_{0.64}P_{0.36}$ 6000Å/ InP 2840Å cap
Bottom: experimental data

Several InGaAsP structures were grown by gas-source MBE, using a modified Varian Gen-II MBE system with thermally cracked arsine and phosphine as the group V sources, and solid sources for the group III elements and dopants. All samples were grown on semi-insulating (001) InP substrates at a growth temperature of 440° C. The structure consisted of a 600 nm lattice matched undoped InGaAsP (λ = 1.33 μm) quaternary active layer surrounded by InP cladding layers.

It was found that significant arsenic incorporation into InP layers adjacent to layers containing a high percentage of arsenic can occur both because of leakage when the arsine gas line is open but the cracker shutter is closed, and because of residual arsenic remaining after the arsenic source (shutter and gas line) is closed. Including InAsP layers due to both of these effects in the simulation results in a much closer match to the experimental data, as shown in Fig. 2. For the first device sample examined, the arsenic concentration was 13% in the section of the underlying InP buffer layer grown with the arsine gas line open. In the InP layer above the quaternary, the arsenic concentration was smaller, starting at about 5% and decreasing from there, but some arsenic incorporation was present in almost the entire top layer. These InAsP layers significantly change the X-ray profile of the complete structure, resulting in a very complex X-ray curve that can mimic the effect of various composition nonuniformities and lead to the seeming paradox between the PL and X-ray data. Adjusting the duration of growth interruptions between layers that contain arsenic and those that do not contain arsenic is effective in controlling this problem without decreasing the structural quality of the material.

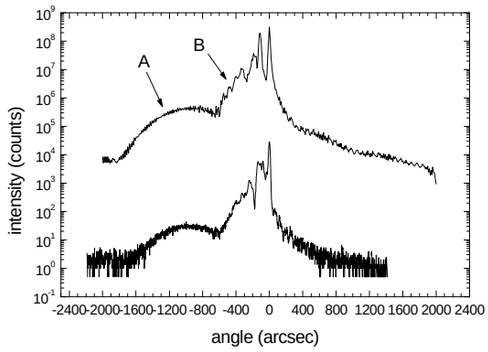

Fig. 2. X-ray data and new simulation for device structure shown in Fig. 1. Top: simulation of quaternary layer with As in last 2 min of buffer and decreasing As in cap layer. Simulated structure is $InAs_{0.13}P_{0.87}$ 260Å/ $In_{0.71}Ga_{0.29}As_{0.64}P_{0.36}$ 6000Å/ $InAs_{0.05}P$ 710Å/ $InAs_{0.03}P$ 710Å/ $InAs_{0.02}P$ 1420Å
Bottom: experimental data